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A broad band radiation source for optical absorption spectroscopy measurements in single shot transient media

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In order to investigate the post-arc period and the hot gas regions surrounding the electrical arc in circuit breakers, a broad band radiation source has been developed to perform absorption spectroscopy measurements. The radiation spectrum has been characterised both temporally and spectrally in order to determine the best operating conditions to produce an intense and continuous radiation spectrum. Absorption tests have been performed on the hot gas region of a low voltage rail gap circuit breaker.

1. Introduction

Optical absorption spectroscopy (OAS) is a technique commonly used to diagnose media where light emission is either missing or very weak. The use of this technique for rapidly transient media produced on a single shot basis or at very low and irregular repetitive rate, needs high spectral intensity sources presenting a very broad band spectral emission at the same time.

In order to perform such absorption measurements, a high intensity and very broad band transient source was developed. It consisted in an electrical discharge using the well-known Z-Pinch effect. At plasma ignition, fast discharge current flows in a very thin layer, called current sheet, at the surface of the inner wall of a cylindrical tube. This current sheet is driven by a self-generated Lorentz force towards the tube axis. When the current sheet collapses on the axis, the plasma becomes very dense due to a snowplow effect during compression, which drives all the particles towards the axis. In addition the plasma temperature strongly increases as a result of the conversion of the current sheet kinetic energy into thermal energy at the moment of collapse. This moment is referred to as the pinch time. With appropriate initial conditions, the continuous plasma radiation becomes extremely intense at the pinch time while the spectral lines are totally smeared out in the continuum background. Under our specific conditions, an electron density N_e above 10^{20} cm^{-3} is obtained. Consequently, on the one hand the bremsstrahlung and the radiative recombination, both depending on N_e^2 , produce a very intense continuous emission and, on the other hand the spectral lines are strongly broadened by the Stark effect. In addition light observation along the tube axis allows to obtain a large optical thickness for both the continuous radiation and the spectral lines so that the global emitted spectrum is very close to the black body radiation at a temperature of about 80 000 K [1].

Investigations of arc re-strike phenomena were performed on a low voltage rail-gap circuit breaker by C. Fiévet et al [2]. It appears that the hot gas left behind the moving arc plays a major part in the re-strike process. The OAS measurement that enable to

determine the composition and temperature of this gas and the concentration of each species, can provide valuable information for understanding of the arc re-strike phenomena. Tests of absorption measurements have been performed on a similar circuit breaker.

2. Z-pinch investigation

The experimental set-up of the Z-pinch is given in [1]. A streak camera is used to observe the plasma self-compression dynamic in Quartz tube. Optical fibre is used to collect plasma light through hole drilled in the centre of electrode. Both photo-diode signal and Streak camera photo show a giant light peak at the pinch time.

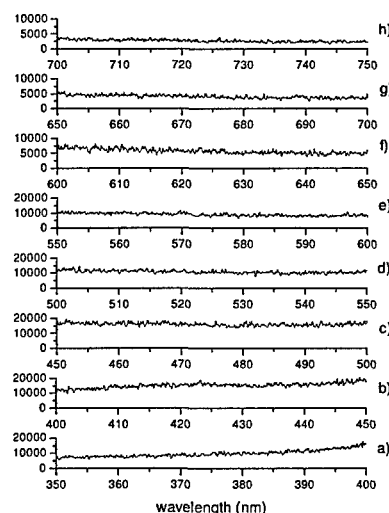


Fig. 1. Spectrum in the 350-750 nm range at pinch time.

Time resolved end-on spectral measurements in a spectral range from 328 to 340 nm were performed at different instants during the discharge [1]. The spectra are recorded by a spectrometer ACTON 750 coupled with an intensified 2D CCD. Between 2 and 4 μs , the spectral intensity is very weak and negligible. At 6 μs , the plasma arrives on the axis and the emission in this wavelength range is dominated by Ar III lines (328.61, 331.16, 333.61, 334.47, 335.84 nm, etc.). At pinch time included in the observation period from 8 to 10 μs , the

continuum emission becomes very intense while the spectral lines totally disappear due to the high electron density of the plasma. The plasma radiation is very close to a black body emission at this moment. At times between 14 and 16 μ s, Ar II lines (335.09, 337.7, 338.85 nm, etc.) appear but Ar III lines are still present.

At the pinch time, the whole spectrum in the range 350 to 750 nm is shown in Fig. 1. The emission is flat, so it is very suitable for atomic or molecular absorption measurements.

3 Absorption measurement

Absorption measurement was performed with the experimental set-up designed for investigation of the breaking operation in low voltage circuit breakers [1-2]. One ms after the beginning of the current, a mobile contact is opened, and an arc is created in circuit breaker. Due to the Lorentz force, the arc moves away between the two rails towards the quenching area. As there is a strong erosion of the copper electrodes and, possibly, of the limiting walls, the hot gas behind the arc is composed of air, copper, and other species usually carbon and hydrogen since the walls are generally made of plastic material. Because this hot gas plays an important role in the arc-re-strike phenomenon, its investigation is useful for the modelling and the design of the circuit breaker.

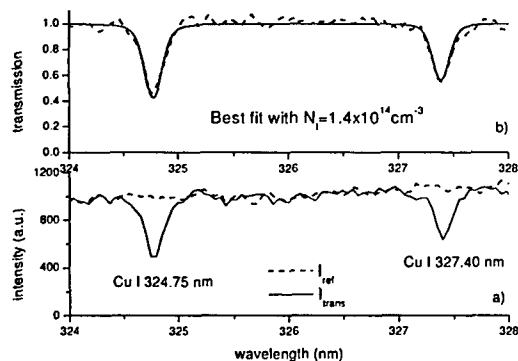


Fig. 2. a) Absorption spectrum of copper atom resonance Cu I lines 324.75 and 327.40 nm; b) transmission spectra and its best fit.

In Fig. 2-a), an absorption spectrum of the two copper resonance Cu I lines Cu I 324.75 and 327.40 nm is given. I_{ref} is the non-absorbed incident intensity and I_{trans} is the transmitted intensity. This measurement was performed at a position of 6 cm from the arc ignition area and about 1 ms after the arc has passed through. The relative intensity $R_M = I_{trans}/I_{ref}$ is plotted in Fig. 2-b). The theoretical value of the absorption coefficient α_T is given by the following relation, where $S(\lambda)$ represents the normalised true line profile :

$$\alpha_T(\lambda) = \frac{\lambda^4 A_{ul}}{8\pi c} \frac{g_u}{g_l} N_l S(\lambda)$$

Where the physical quantities are represented by the symbol commonly used and the stimulated emission term is neglected.

The best fit shown in Fig. 2-b) yields copper atom density of about $1.4 \times 10^{14} \text{ cm}^{-3}$ and a half width of 0.016 nm (the same width was attributed to these two lines because they belong to the same multiplet). In our case the uncertainty can be estimated to be 30%.

A Swan bands (0,0) and (1,1) absorption spectrum of the C_2 obtained in this experiment is shown in Fig. 3. Theoretical simulation of the rotational and vibrational structure of these molecular bands yields a C_2 concentration of about $1.3 \times 10^{15} \text{ cm}^{-3}$ and a rotation temperature of about 3000 K. The uncertainties are estimated to be also about 30%.

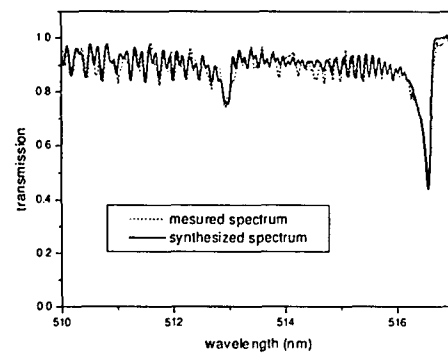


Fig. 3. C_2 absorption spectrum of Swan bands (0,0) and (1,1) (experiment and simulation).

4. Conclusion

A Z-pinch light source has been developed to perform optical absorption spectroscopy. Optimal working conditions have been set to obtain an intense and continuous radiation spectrum at the pinch time. Feasibility tests of optical absorption spectroscopy using this source have been performed on the hot gas and vapour produced in a low voltage rail gap circuit breaker. These rather simple measurements already provide quite interesting information about the hot gas left behind the arc.

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5. References

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